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DETAILED COMPONENT DESIGN FOR A COMPACT ENVIRONMENTAL ANOMALY SENSOR (CEASE): MECHANICAL DESIGN AND CALIBRATION

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13. ABSTRACT *(Maximum 200 words)*

The outer space environment experienced by a modern, electronically sophisticated spacecraft can be very hostile due to interactions between its complex, sensitive electronics systems and the naturally occurring energetic particle population indigenous to the solar system. The Compact Environmental Anomaly Sensor (CEASE) is being developed as a small, low-power device to monitor space "weather" and provide autonomous warnings of conditions that may cause operational anomalies in a host spacecraft. CEASE uses a two-element solid-state telescope, two radiation dosimeters and one SEU detector to sample critical energetic particle fluxes. It uses a sophisticated real-time processing program that can forecast hazardous environmental conditions before they effect the spacecraft. The spacecraft, in turn, can re-prioritize its operations, inhibit any anomaly sensitive operations such as attitude adjustments, or take any other prudent action suggested by the potential of erratic conditions.

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1. INTRODUCTION

This document is the Final Report for the CEASE Program carried out by Amptek, Inc. under the Air Force contract F19628-90-C-0159.

The goal of this program was to develop an instrument for the real-time detection of space environment hazards that can affect Air Force satellites. The hazards of concern are radiation damage, single event upsets and charging of dielectric surfaces and volumes. An important aspect of the CEASE design was to build a small, light-weight instrument with minimum power and telemetry requirements, so that that CEASE can become a standard diagnostic element on operational spacecraft.

The CEASE design described in this report has been manufactured by Amptek, Inc. and two flight units and one engineering models have been delivered to the Air Force Phillips Laboratory on 30 April 1996.

2. INSTRUMENT OVERVIEW

CEASE is a small, light-weight, low-power instrument, designed to provide to the host spacecraft (S/C) information on possible ***environmental hazards*** of 1) spacecraft and dielectric charging, 2) total radiation dose 3) radiation dose rate and 4) single event upsets. The S/C operator can use this information to take appropriate action to avoid endangering the mission. The instrument will also provide, if requested, detailed data on particle fluxes incident on the spacecraft over the 72 hours prior to the request. This feature will allow the spacecraft operator, once an anomaly has occurred, to have sufficient data to analyze and understand the cause of the anomaly.

The goal of the CEASE program is to place CEASE instruments on Air Force and other satellites to routinely provide environmental hazard warnings and S/C state of health monitoring. CEASE is designed to be a standard, operational instrument for general use on all spacecraft. The mechanical and electronic design of the instrument was focused on the small-size, low-power requirement, high reliability and radiation hardness, to allow the incorporation of CEASE into virtually any spacecraft and mission. The instrument's on-board intelligence permits long-term, unattended operation of the instrument, giving the S/C operator as much, or as little, information as needed.

2.1 Information Provided by CEASE

The CEASE instrument can operate in two modes, Engineering and Science Modes. The Engineering Mode operation is intended for use on operational satellites, where CEASE will operate autonomously and provide data to the S/C only when requested, perhaps very irregularly and/or infrequently. The Science Mode operation is intended for use on S/C where sufficient S/C resources are available to regularly telemeter the detailed science data collected by CEASE.

In Engineering Mode, CEASE provides eight 4-bit (16 level) logarithmically spaced Status Registers (SR) and ten 1-bit Warning Flags (WF) to the S/C. This information permits the operator to assess environmental hazards and take any required corrective actions. The minimum and maximum values of the status registers are set in software and are mission specific. The eight Status Registers are:

1) <u>Surface Dose</u> (SUD) - The radiation dose received by devices with a minimum amount of shielding, such as solar panels. This register is useful in determining the expected efficiency of solar panels through the duration of a mission.

2) <u>Low Shield Dose</u> (LSD) - The radiation dose received by electronic devices shielded behind an equivalent of 0.08 in of aluminum. This register is useful in determining when lightly shielded electronic components are reaching the limits of their radiation hardness.

3) High Shield Dose (HSD) - The radiation dose received by electronic devices shielded behind an equivalent of 0.25 in of aluminum. This register is useful in determining when relatively heavily shielded electronic components are reaching the limits of their radiation hardness.

4) SEU Events (SEU) - The value of this register corresponds to the probability of an upset of a typical IC as a result of bombardment by high energy protons and heavy ions. This flag is useful in identifying the times when the SEU probability is high, and high risk activity, such as attitude control, should be avoided.

5) Surface Dielectric Charging (SDC) - The value of this register corresponds to the threat level of charging of dielectric materials near the spacecraft surface (thermal blankets, exposed wires). This flag is useful in identifying the times when electric discharges at the S/C surface may occur. These discharges may damage delicate surfaces and introduce noise and spurious signals into the S/C circuitry.

6) Deep Dielectric Charging (DDC) - The value of this register corresponds to the threat level of charging of dielectric materials in the interior of the spacecraft. This flag is useful in identifying the times when electric discharges in well shielded signal cables may occur. These discharges may introduce noise and spurious signals into the S/C circuitry.

7) Low Shield Radiation Dose Rate (LSR) - The value of this register corresponds to the radiation dose rate received by electronic devices shielded behind an equivalent of 0.08 in of aluminum. This register is useful in determining when lightly shielded radiation dose rate sensitive components may malfunction.

8) High Shield Radiation Dose Rate (HSR) - The value of this register corresponds to the radiation dose rate received by electronic devices shielded behind an equivalent of 0.25 in of aluminum. This register is useful in determining when heavily shielded radiation dose rate sensitive components may malfunction.

Eight of the ten Warning Flags correspond to the Status Registers. If any of the Status Register values exceeds a pre-set limit, the corresponding Warning Flag is set ON. The Warning Flag limit can be set by ground command. The additional flags are the electron fluence flags. If the integrated electron SDC or DDC fluence over the past H hours exceeds the a pre-set limit, the corresponding fluence Warning Flag is set ON. The fluence limits and the value of H can be set by ground command.

In order to facilitate the analysis of anomalies, CEASE stores the previous 72 hours of data in its on-board memory (**History Data**). The data includes proton and electron fluxes in various energy ranges and incremental radiation dose information and is stored with 15-20 minute resolution. History Data is made available to the S/C on command. Typically, the SC operator will request History Data once an anomaly has occurred, and an investigation into the cause of the anomaly is in progress. History Data is available only in Engineering Mode.

In Science Mode, CEASE can furnish extensive, high-resolution electron and proton flux data as well as radiation dose and dose rate data with time resolution adjustable between 5 and 60 seconds (**Science Data**). The actual Science Data time resolution depends on the available S/C telemetry. CEASE produces 56 bytes of science data per readout cycle.

2.2 Size and Power Requirements

The CEASE instrument is contained in a 10 x 10 x 8.4 cm^3 (4 in x 4 in x 3.2 in) Al housing It has a mass of approximately 1 kg and requires less then 1.5 W of power to operate with an RS-422 S/C interface. The exterior view of the CEASE box is shown in Figure 1. The x's mark the location of the centers of DD1 and DD2 dosimeter detectors which are mounted on the top (DOS) printed circuit board.

2.3 Sensor Complement

The CEASE instrument has four sensors, two independent solid-state radiation dosimeters, one SEU sensitive detector and an energetic particle telescope consisting of two solid state detectors. The radiation dosimeters provide information about the radiation doses and dose rates received by components behind different amounts of shielding (LSD, HSD, LSR and HSR). The SEU detector provides information about the probability of single-event-upset events in the electronic circuitry (SEU). The telescope provides information about the energy-dependent flux of electrons with energies above 60 keV and protons with energies above 3 MeV (SDC, DDC, and SUD). A cross section view of CEASE, showing the circuit board locations and the telescope location is displayed in Figure 2.

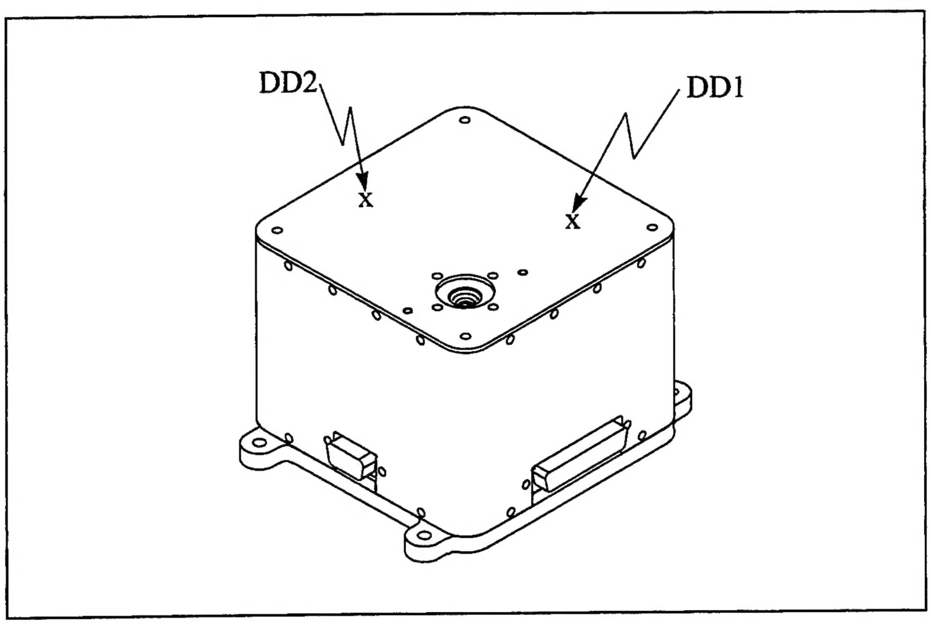

Figure 1. Exterior view of the CEASE instrument.

3. PARTICLE DETECTORS

The two CEASE dosimeter detectors DD1 and DD2 are located in the top instrument PC board (DOS PCB, see section 5, INSTRUMENT ELECTRONICS). DD1 has 0.08 in of Al shielding above it, while DD2 has 0.25 in of Al shielding. The SEU detector, DD3, is mounted on the TEL PC board, located immediately below the DOS PC board. All three detectors are identical Hamamatsu S3590-06, 500 μm thick, p-i-n photodiodes. The sensitive detector area is a 9 mm x 9 mm square. CEASE S/N 001 and 002 units will be initially equipped with the 81 mm^2 area detectors. If one of these units is scheduled to be sent into a high-radiation orbit, it would be desirable to replace the dosimeters with smaller area detectors. We have obtained 13 mm^2 area photodiodes from Hamamatsu for that purpose.

The two telescope detectors, DFT and DBT, are located inside the telescope enclosure, which shields them from out of aperture protons with energies below 60 MeV. The telescope opening aperture is covered by a 0.009 mm thick Al foil which prevents electrons with energies below 30 keV and protons with energies below 800 keV from reaching the front telescope detector (DFT). The back telescope detector (DBT) is located immediately behind the DFT. The telescope detectors are solid state PIPS detectors purchased from Canberra. DFT is 25 mm^2 in area and is 150 μm thick, while DBT is 50 mm^2 in area and is 700 μm thick.

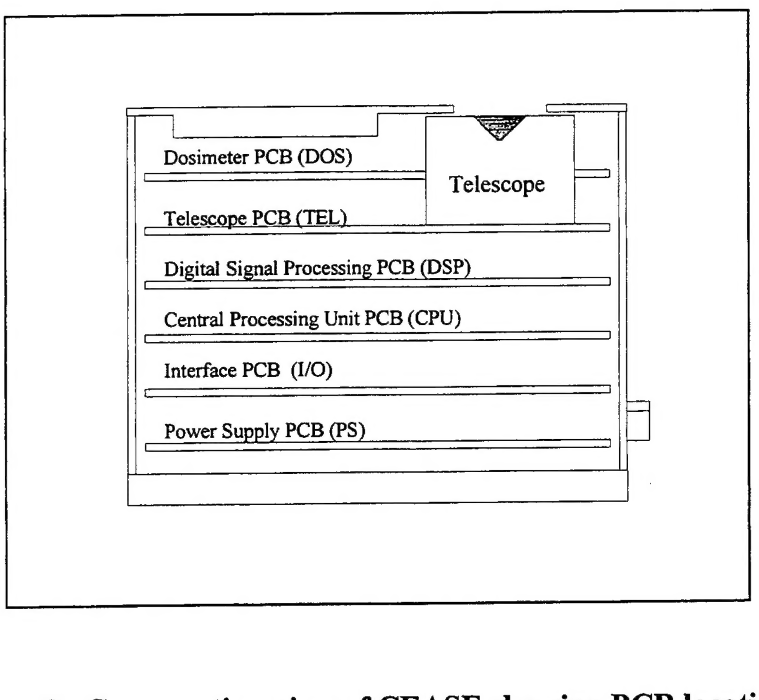

Figure 2. Cross section view of CEASE showing PCB locations.

4. DATA PROCESSING AND TELEMETRY

4.1 Dosimeter Data Processing

Particles which penetrate the shielding strike the dosimeter detectors and deposit energy in the sensitive volume. The detectors are connected to charge sensitive pre-amplifiers which produce a voltage proportional to the deposited energy. This voltage is further amplified and measured by an analog-to-digital converter (ADC). The resulting digitized value can be calibrated to be read out in MeV of energy deposited in the sensitive detector volume. This value can in turn be used to calculate the radiation dose rate or total dose received by the detector.

The dose can be further divided into dose due to protons with E < 100 MeV (HILET) and dose due to electrons and protons with E > 100 MeV (LOLET). The energy loss by electrons and high energy protons in the dosimeter detectors is limited to about 1 MeV, while lower energy protons deposit between 1 and 10 MeV. Use of the ADC to digitize the particle energy loss, allows the HILET and LOLET doses to be computed by the CEASE microprocessor.

The SEU detector records events which result in very large energy deposition in the DD3 detector. These types of events are thought to be responsible for SEU in electronic devices. DD3 is physically identical to the dosimeter detectors (DD1 and DD2) but its electronic circuits are very different. The amplified DD3 output signal voltage is compared to a single voltage threshold which corresponds to an energy deposition of over 50 MeV. Events that lead to voltages exceeding this threshold are counted as SEU-type events.

4.2 Telescope Data Processing

The telescope consists of two detectors mounted coaxially, one behind the other. Particles incident on the entrance aperture strike the front detector (DFT) and, if they have sufficient energy, the back detector as well. The pattern of energy deposition in the two detectors is used to identify the particle type and determine the particle's energy. In general, electrons with energies less than about 350 keV and protons with energies less than about 4.5 MeV will stop in DFT and deposit all of their energy in that detector. Particles with higher energies will deposit energy in both detectors. A schematic diagram of the telescope configuration is shown in Figure 3.

The telescope detectors are connected to charge sensitive pre-amplifiers and main amplifiers. These circuit elements convert the energy deposited in the detector to a voltage pulse, whose amplitude is proportional to the amount of deposited energy. The pulse amplitude from each detector is compared to a set of eight voltage thresholds and the results of the comparisons are used to place the event pulse height in one of 80 logic boxes (LB). The CEASE processing algorithms then convert counts in the various LB's to incident electron and proton fluxes and calculate SDC, DDC and SUD Status Registers. The thresholds and logic boxes are shown in

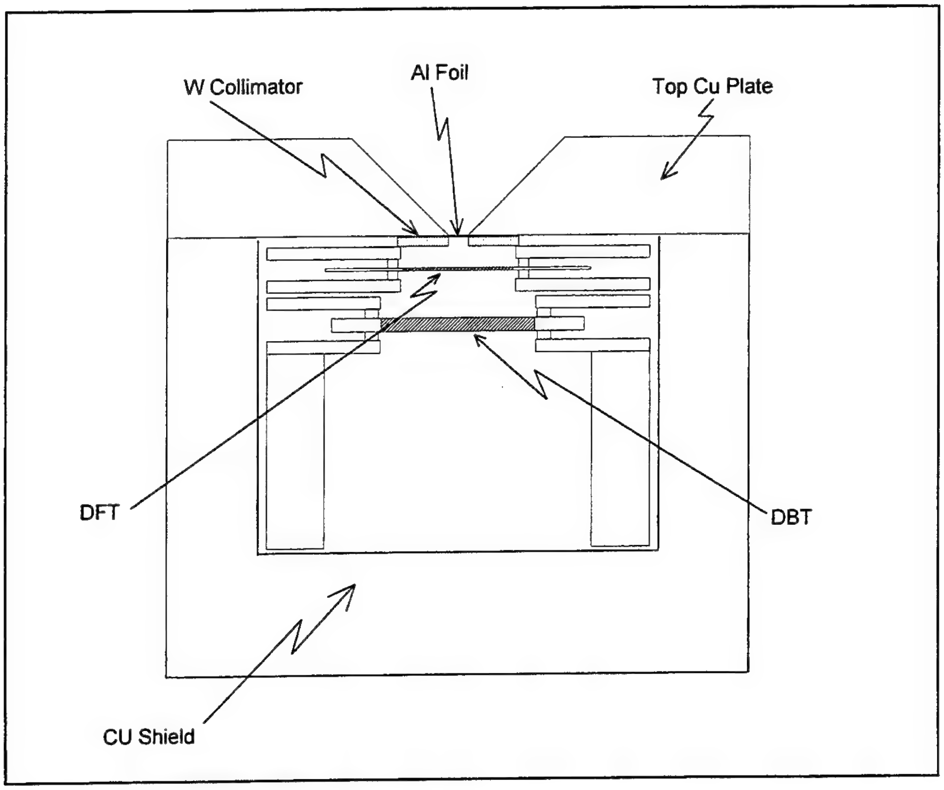

Figure 3. Schematic diagram of the CEASE telescope.

Figure 4. DFT thresholds are labeled TFA through TFH and the DBT thresholds are labeled TBA through TBH. The LB's are labeled with (m,n) where m and n designate the DFT and DBT thresholds. For example, LB (2,1) indicates that DFT energy deposition fell between threshold #2 (TFB) and #3 (TFC) and the DBT energy deposition fell between threshold #1 (TBA) and #2 (TBB). Note that all (m,0) LB's are events with energy deposition only in DFT, while (0,n) LB's are events with energy deposition in DBT only. All other LB's indicate some energy lost in each detector. LB's (6,n), (7,n), (m,5), (m,6) and (m,7) are not labeled due to space limitations.

The incident particles and their energies can be identified from the LB's. The thick line shown in Figure 4 shows the pattern of energy deposition due to incident protons (arrows show where protons with given incident energy fall on the curve). The pattern of electron energy deposition is more complex and is not shown in the plot. Analysis of the electron energy deposition pattern shows that events that contribute to the SDC SR will be found in LB's (1,0), (2,0) and (3,0), while DDC events will tend to be in LB's (4,0), (3,1), (2,1), (1,1), (1,2) and (1,3). Proton fluxes can be extracted from the LB's surrounding the proton-energy deposition curve.

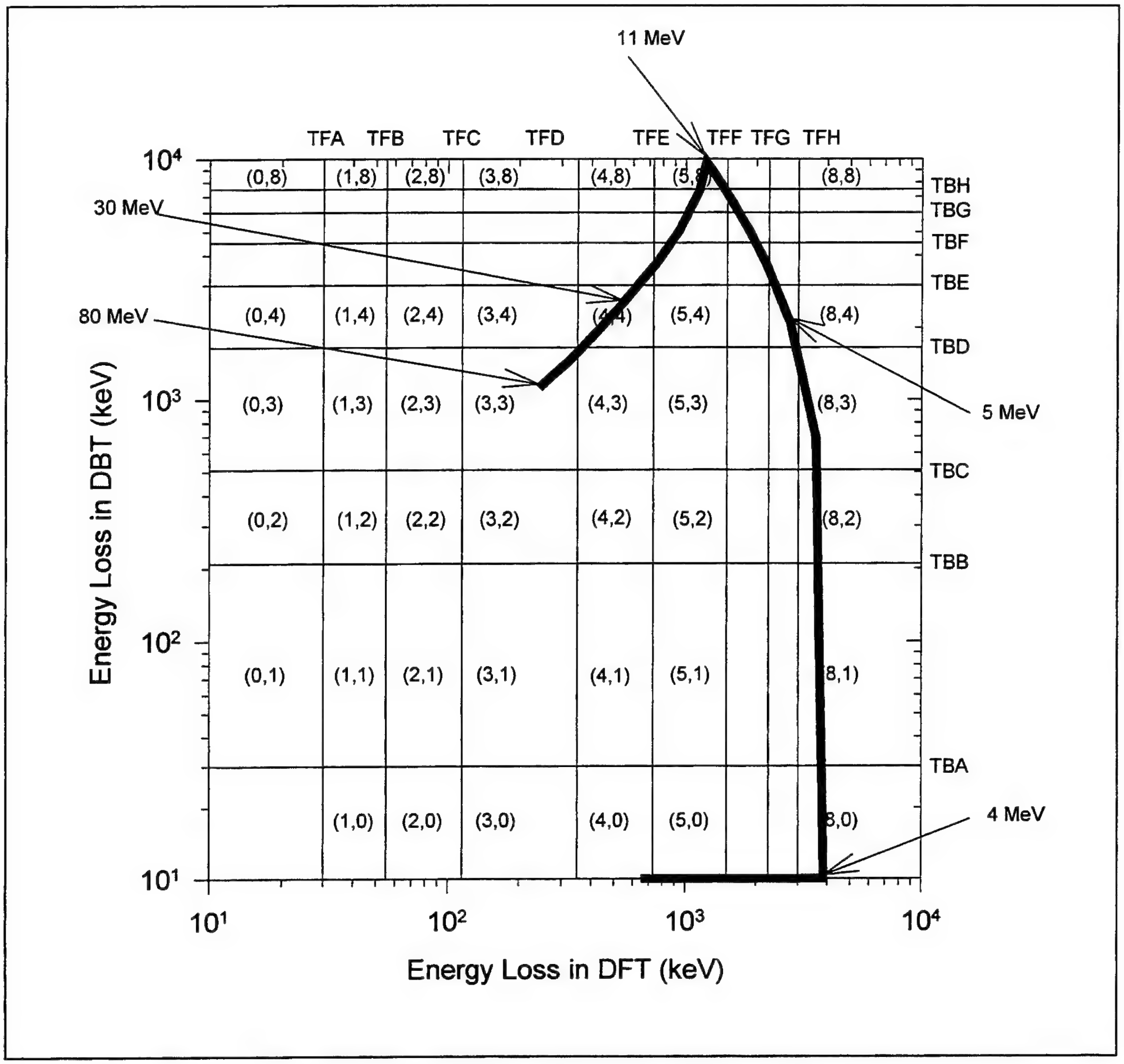

Figure 4. Energy loss in DFT and DBT. Thick curve is proton energy deposition.

4.3 Engineering Mode Telemetry

During Engineering Mode operation, the electron and proton flux data and the dose and dose rate data are processed to arrive at the eight Status Registers and the ten Warning Flags (WF's). This computation is carried out once every sixty seconds. The information is made available to the S/C and will be sent, if requested, in the form of an eight-byte Engineering Telemetry packet. The packet bit assignments are shown in Table 1.

Table 1. CEASE Engineering Mode telemetry packet.

Byte	Name	Bits	Description
1	WF-A	b_i; i = 0..7	If $WF_n = 1$ then $b_{(n-1)} = 1$, otherwise $b_{(n-1)} = 0$
2	WF-B	xyzb_i; i = 3..7	x(y) = 1 if $WF_{9(10)}$ =1, otherwise x(y) = 0 If any WF_i has changed from 0 to 1 since last SC request for data z = 1, otherwise z = 0. i = 3..7; if z = 1 and any of the WF_1 through WF_5 values have changed from 0 to 1, the ith bit is set to 1, otherwise it is set to 0.
3	WF-C	b_i: i = 0..7	i = 0..4; if z = 1 and any of the WF_6 through WF_{10} values have changed from 0 to 1, the ith bit is set to 1, otherwise it is set to 0. i = 5-8; spare
4	SR12	xxxxyyyy	xxxx = SR_1; yyyy = SR_2
5	SR34	xxxxyyyy	xxxx = SR_3; yyyy = SR_4
6	SR56	xxxxyyyy	xxxx = SR_5; yyyy = SR_6
7	SR78	xxxxyyyy	xxxx = SR_7; yyyy = SR_8
8	SOI	xxxxxxxx	Multiplexed housekeeping data byte

The first three bytes contain information about the WF's. These bytes are used to alert the S/C if any WF's are currently set to 1 or if any WF's were set to 1 (and possibly reset to 0) since the last S/C data request. Bytes 4 through 7 contain the eight four bit SR's and the last byte contains multiplexed housekeeping information.

4.4 Science Mode Telemetry

In Science Mode, CEASE can send to the S/C telemetry stream a detailed listing of measured particle fluxes and radiation dose rates. The Science Data packet will contain 56 or fewer bytes and be sent to the S/C once per fixed time interval. The interval can be set to be 5, 10, 20, 30 or 60 seconds. A preliminary listing of the Science Mode telemetry packet is shown in Table 2.

Table 2. Preliminary CEASE Science Telemetry Listing

Byte	Contents	Comments	Byte	Contents	Comments
1	L1 Flux	DD1 LoLET	29	LB (6,2)+(7,2)+(8,2)	
2	L1 Dose	DD1 LoLET	30	LB (6,3)+(7,3)+(8,3)	
3	H1 Flux	DD1 HiLET	31	LB Sum No. 1	
4	H1 Dose	DD1 HiLET	32	LB Sum No. 2	
5	L2 Flux	DD2 LoLET	33	LB (5,4)+(5,5)+(5,6)	
6	L2 Dose	DD2 LoLET	34	LB (5,7)+(5,8)	
7	H2 Flux	DD2 HiLET	35	LB (4,4)	TEL - Protons
8	H2 Dose	DD2 HiLET	36	LB (4,5)	E > 20 MeV
9	SEU Counter	DD3 (Hi or Low)	37	LB (4,6)	
10	LB (1,0)	TEL - Electrons	38	LB (4,7)	
11	LB (2,0)	All energies	39	LB (4,8)	
12	LB (3,0)		40	LB (3,4)	
13	LB (4,0)		41	LB Sum No. 3	
14	LB (1,1)		42	Status Byte 1	see Note 1
15	LB (2,1)		43	Status Byte 2	see Note 2
16	LB (3,1)		44	SR1 and SR2	see Note 3
17	LB (4,1)		45	SR3 and SR4	see Note 3
18	LB (1,2)		46	SR5 and SR6	see Note 3
19	LB (2,2)		47	WF	see Note 4
20	LB (3,2)		48		
21	LB (1,3)		49		
22	LB (2,3)		50		
23	LB (3,3)		51	DPU Status Byte	
24	LB (5,0)	TEL - Protons	52		
25	LB (6,0)	E < 20 MeV	53	Frame Cntr. Byte 1	
26	LB (7,0)		54	Frame Cntr. Byte 2	
27	LB (8,0)		55	Sync Byte 1	
28	LB (6,1)+(7,1)+(8,1)		56	Sync Byte 2	

Logic Box (LB) Sums:

Sum 1: (6,4)+(7,4)+(8,4)+(6,5)+(7,5)+(8,5)
Sum 2: (6,6)+(7,6)+(8,6)+(6,7)+(7,7)+(6,8)+(7,8)
Sum 3: ((0,4)+(0,5)+(0,6)+(0,7)+(0,8)

Notes:

1) Status Byte 1: abcdexxx - Detector threshold status, 0 if low and 1 if high. a-DFT, b-DBT, c-DD1, d-DD2, e-DD3 and xxx-don't care.
2) Status Byte 2: abcdxxxx - Detector leakage current monitor, 0 if OK and 1 if high. a-DFT, b-DBT, c-DD1, d-DD2 and xxxx-don't care.
3) 2 4-bit Status Registers (SR) from last SR calculation per each of the three bytes (Bytes 44, 45 and 46). For example Byte 44: xxxxyyyy - xxxx is SR1 and yyy is SR2
4) Byte 47 contains the current values of the eight one-bit Warning Flags.

5. INSTRUMENT ELECTRONICS

The electronic circuitry of the CEASE instrument is contained on six 3.5 in x 3.5 in circuit boards or PCB's (see Figure 2). The board immediately underneath the top instrument cover is the DOS PCB which contains DD1 and DD2 sensors as well as their analog signal processing circuitry. The next board down is the TEL PCB which contains DD3 and the connections to the telescope detectors, DFT and DBT, and the analog signal processing electronics for these detectors. The DSP PCB is the third board down. It contains the digital processing circuitry and memory for all the CEASE detectors. The CPU board, containing the microprocessor, additional instrument memory and associated glue logic is located under the DSP PCB. The I/O PCB is the fifth board down. This board can be configured for RS-422 or 1553B S/C interface. The PS PCB is the bottom board. This PCB contains the DC/DC converter and HV power supply.

5.1 Detector Analog Signal Processing

The SEU detector (DD3) has the simplest processing circuitry (see block diagram shown in Figure 5). The signal from the detector is capacitatively coupled to the hybrid Amptek A-111 preamplifier-discriminator device which contains both amplification and discrimination circuits. All signals that exceed a fixed threshold are scaled in counter located on the CPU board. No other pulse height analysis is performed on this signal. The HV filter circuit prevents electronic noise from the power supply from affecting the detector output signal.

The analog processing of the telescope signals results in the development of two signals, a fast pulse suitable for timing work and a slow, shaped pulse for pulse-height discrimination work

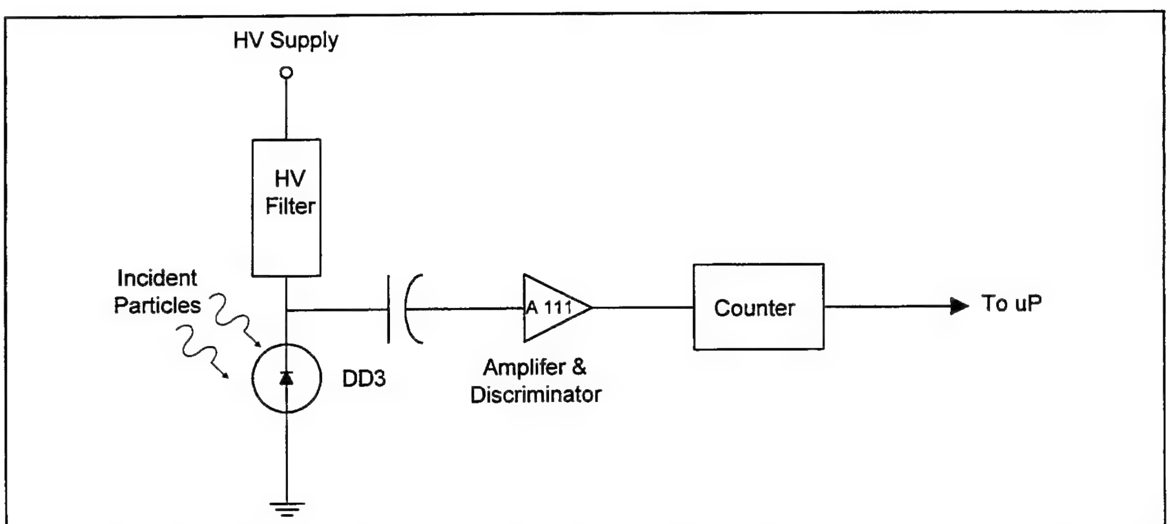

Figure 5. Block diagram of DD3 detector electronics.

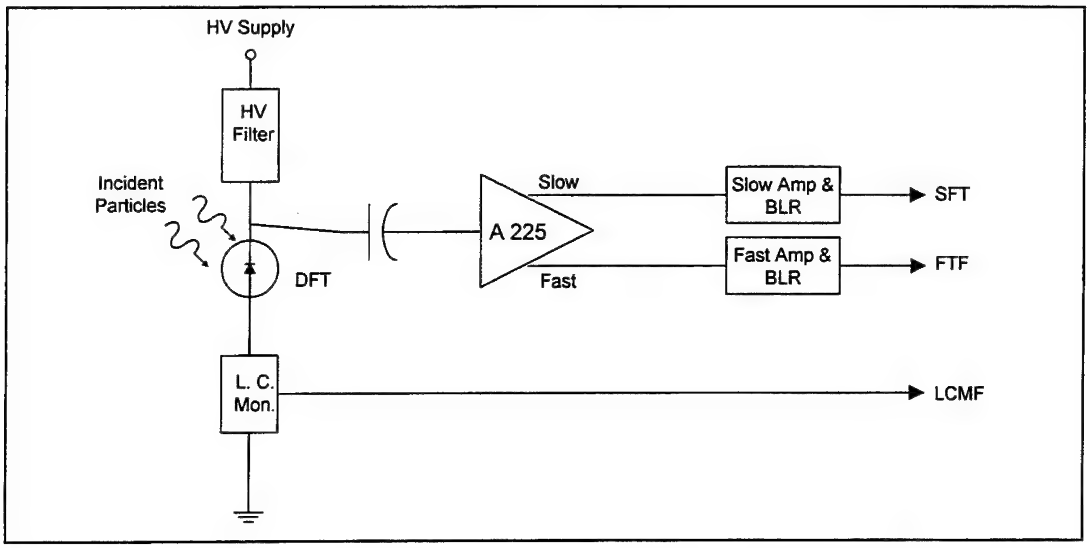

Figure 6. Block diagram of the DFT detector analog signal processing circuit.

(see Figure 6 for the block diagram of the DFT circuit). Both signals are derived from the hybrid Amptek A-225, charge sensitive preamplifier and shaping amplifier device. The leakage current monitor (L.C. Mon. in Figure 6) measures the detector leakage current and, if it exceeds a preset value, sends a signal to the microprocessor to warn of possible detector malfunction. The processing circuit for the DBT detector is identical and produces output signals STB, FTB and LCMB (analogous to the FTB, FTF and LCMF signals) for further digital processing.

The analog signal processing of the dosimeter detectors (DD1 and DD2) is slightly more complex and requires the use of a novel hybrid components developed for the CEASE program (DD1 circuit is shown in Figure 7). The added complexity is due to the fact different gains are required to process electron and proton pulses. In order to save on power and mass, Amptek, Inc. developed a unique, real-time gain switching circuit. The A-225 device is used as a preamplifier and shaping amplifier as for the telescope detectors. The fast A-225 output is sent to the custom designed Fast Amplifier and Baseline Restorer hybrid device, which performs a fast (50 ns rise time) amplification of the signal and passes it to the Gain Control (GC) part of the circuitry. The GC determines if the detector signal exceeds a preset threshold and sets the custom designed Slow Amplifier circuit gain to a lower (higher) setting if it exceeds (does not exceed) the threshold. The gain switch is made quickly enough to be performed before the Slow Amplifier begins to process the signal. Processing of the DD2 signal is identical to the DD1 processing and results in production of SD2, GAIN2, FD2 and LCM2 signals for further digital processing.

5.2 Digital Signal Processing

The CEASE digital signal processing relies heavily on the use of the Field Programmable Gate Array (FPGA). These highly flexible devices can be configured to replace many digital elements and, thereby, save a substantial amount of power and PCB area. A block diagram of the digital processing circuitry is shown in Figure 8. The Digital Peak Detector, Window

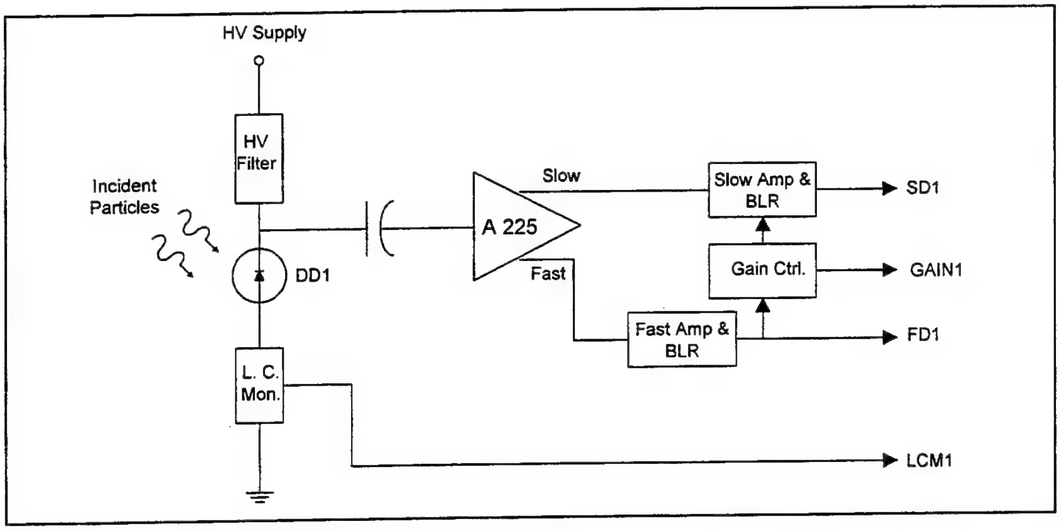

Figure 7. Block diagram of the DD1 detector analog signal processing circuit.

Discriminators, Coincidence Circuitry and Memory Control element functions, shown in the block diagram, are all executed in the CEASE FPGA's.

Both dosimeter detectors share a single ADC and each detector is operated with a 50% duty cycle, collecting data for one second and being off-line for one second. The CEASE microprocessor controls the switching between the two detectors through the Multiplexer Unit (MUX). The fast signal (FD) from the on-line detector gates the flash ADC which continuously digitizes the shaped pulse (SD) for 5 μsec at a rate of 10 MHz. The Digital Peak Detector processes the digitized data and determines the peak pulse height, which is proportional to the deposited energy. The gain signal is used to determine the proportionality constant between the digitized peak pulse height value and the deposited energy.

The slow, shaped telescope signals STB and STF are sent to custom-designed hybrid threshold discriminators, which together with FPGA circuitry make up the Window Discriminators. Each detector has eight thresholds for deposited-energy analysis. The fast signals (FTB and FTF) are used to determine if the two detectors fired simultaneously (coincidence resolution time is 500 ns) or if only one telescope detector fired. Both the coincidence and singles telescope counts are used by the CEASE algorithms to determine the SR values.

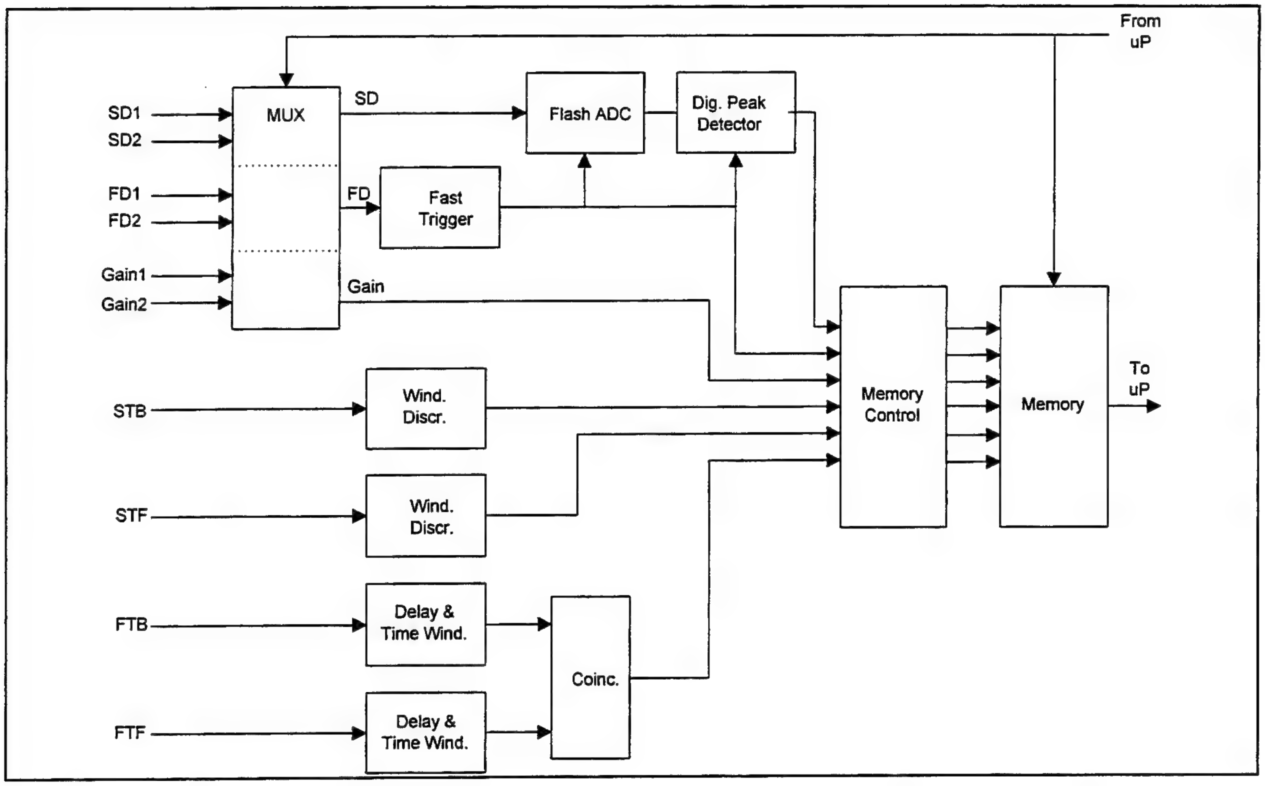

Figure 8. Block diagram of the CEASE digital signal processing.

6. ENVIRONMENTAL TESTING

6.1 Vibration Testing

A mechanical CEASE prototype underwent vibration testing in October, 1995. The unit consisted of the CEASE housing and an interior which included all the PC boards (without components), mounting hardware and a flight configuration telescope. The random vibration profile used for the test (see Figure 9) matched the requirements, specified by TRW, for a Taurus rocket launch of a stacked STEP4/STEP5 spacecraft. The results of the test indicated that 1) the CEASE mounting rails were not stiff enough and needed to be redesigned and 2) the telescope mechanical design was adequate.

The second CEASE vibration test took place in April, 1996, after two flight units (S/N 001 and 002) and one engineering unit (S/N 003) were manufactured. These units included mechanical design changes necessitated by the results of the first test. The vibration testing was carried out on S/N 001 only and included a sine survey (5 to 2,000 Hz, vertical axis only) and

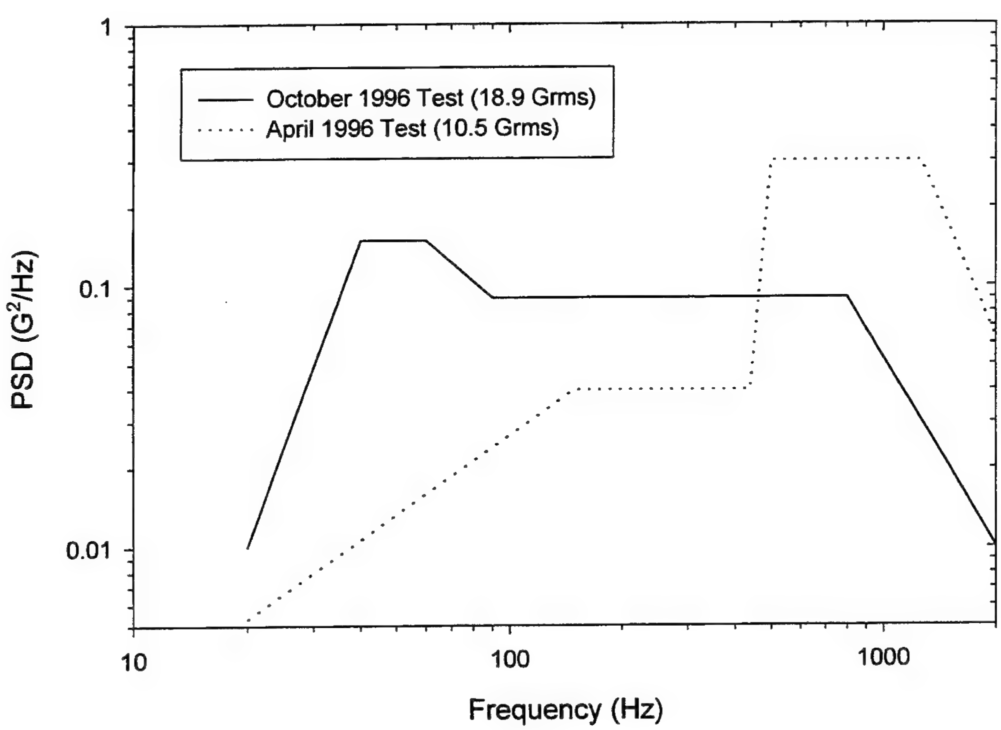

Figure 9. Power Spectrum Density (PSD) diagram of CEASE random vibration tests.

random vibration (all three axes). The sine survey results showed no resonances below 400 Hz. The random vibration profile used for the test (see Figure 9) matched the requirements for a Pegasus rocket launch. The instrument performance was checked before and after the test using radioactive sources. The only change in instrument performance after the test was an increase in the noise counts in the front telescope detector. A check of the instrument revealed that this was due an improper installation of the Faraday shield for the telescope electronics. The problem was fixed and the telescope performance returned to normal.

6.2 Thermal Vacuum Testing

CEASE S/N 001 unit was subjected to thermal vacuum testing to verify proper operation under temperature extremes. Both start-up characteristics and the stability of various analog voltage thresholds were investigated.

The unit was repeatedly successfully started up at various temperatures between -25°C and +41°C with the supply voltage varying between +20 to +32 V. There were no failures in the attempts to start S/N 001 at any temperature or supply voltage.

The operation of the instrument was investigated using both a pulser and a radioactive stimulus. The pulser was a Berkeley Nucleonics Corp. BH-1 Tail Pulse Generator (Rise Time: 0.05 μsec, Fall Time: 1,000 μsec, Polarity: Negative) and it was connected to the CEASE pulser inputs. The radioactive sources were located in the CEASE source holder which was attached to the top of the instrument. The holder contained three sources, ^{137}Cs was located over Dosimeter 2 and a ^{133}Ba source was located over Dosimeter 1 and over the telescope aperture. The pulser provided a check of the CEASE electronics, starting at the input of the pre-amplifier, while the radioactive sources provided a complete, end-to-end, test of the entire system including the solid state detectors.

The stability of the lowest thresholds the telescope detectors was investigated using the tail pulser. A known pulse rate was input to the instrument and the resulting counts were recorded as a function of pulse amplitude. A threshold is defined as the amplitude at which 50% of the input counts are detected by the instrument. The results for the critical front-detector lowest threshold are shown in Figure 10. The change in threshold is less than 6% over the temperature range measured.

The stability of the thresholds of energy channels for both telescope detectors was also investigated using the tail pulser. The energy channel threshold is defined as the pulser amplitude at which the counts are equally distributed in two adjacent channels. Listings of channel thresholds for both telescope detectors are shown in Table 3 and Table 4 (ATT=10 and ATT=Out are pulser amplitude attenuator settings).

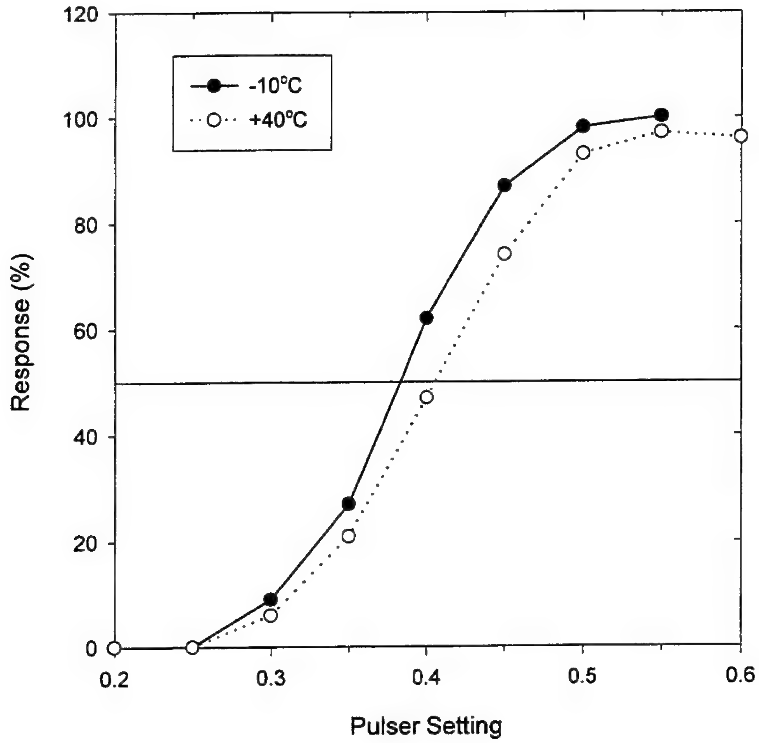

Figure 10. Front Detector Event Threshold.

Table 3. Telescope: Front Detector Thresholds.

Thresh.	Energy (keV)	Temp = -10°C		Temp = +25°C		Temp = + 40°C	
		ATT=10	ATT=Out	ATT=10	ATT=Out	ATT=10	ATT=Out
TFA	38	0.37		0.35		0.40	
TFB	55	0.68		0.67		0.67	
TFC	115	1.43		1.42		1.41	
TFD	250	3.12		3.12		3.14	
TFE	750	9.56	0.83	9.65	0.84	9.70	0.83
TFF	1,500		1.80		1.81		1.81
TFG	2,250		2.75		2.77		2.78
TFH	3,000		----		3.77		3.77

Table 4. Telescope: Back Detector Thresholds

Thresh.	Energy	Temp = -10°C		Temp = +25°C		Temp = + 40°C	
	(keV)	ATT=10	ATT=Out	ATT=10	ATT=Out	ATT=10	ATT=Out
TBA	38	0.70		----		----	
TBB	250	3.92		3.95		3.92	
TBC	500	9.34	0.80	9.45	0.81	9.40	0.80
TBD	1,700		3.00		3.03		3.05
TBE	3,000		5.49		5.55		5.57
TBF	4,500		8.33		8.41		8.43

Dosimeter detector performance was studied using the response to the radioactive sources. The flux counts detected by the dosimeter detectors as a function of temperature are shown in Figure 11. The solid lines are best linear trend fits to the data. The DOS1 and DOS2 trends are both 0.02 % / °C change in the count rate (DOS1 is illuminated with an ^{133}Ba source, while DOS2 is illuminated with an ^{137}Cs source). The ratio of measured dose to flux counts is a measure of the gain of the system. For DOS1 the ratio of dose to flux counts changes by less than 3.5% over the entire temperature range, while for DOS2 the change is less than 1.5%.

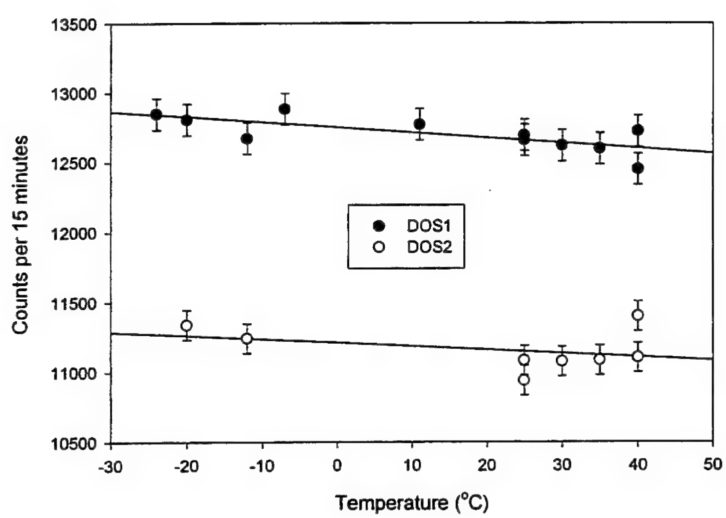

Figure 11. Dosimeter Counts Induced by Radioactive Sources.

7. CALIBRATION DATA

The S/N 003 CEASE instrument telescope underwent calibration with both electron and proton beams at the Goddard Space Flight Center (GSFC) accelerators. Proton beams with energies between 700 and 1,200 keV and electron beams with energies between 55 and 125 keV were used to irradiate the instrument. The instrumental response was measured and recorded as, were beam monitor detector count rates. The monitor detectors were used to normalize the CEASE response to the beam intensity.

The response of the telescope to low energy electrons normal to the telescope aperture is shown in Figure 12. The effective area was obtained by comparing the telescope counts to the measured absolute beam intensity. The error bars are solely due to an estimated 50% uncertainty in the absolute beam intensity and do not reflect additional measurement uncertainties which may be particularly significant at energies near the detector threshold. The solid line is the telescope response calculated using a Monte Carlo ITS electron propagation code.

The response of the telescope to protons was measured as a function of beam energy and its angle of incidence with respect to the telescope aperture. The angular response of the telescope, to an 884 keV proton beam, is shown in Figure 13. The solid line is the calculated response

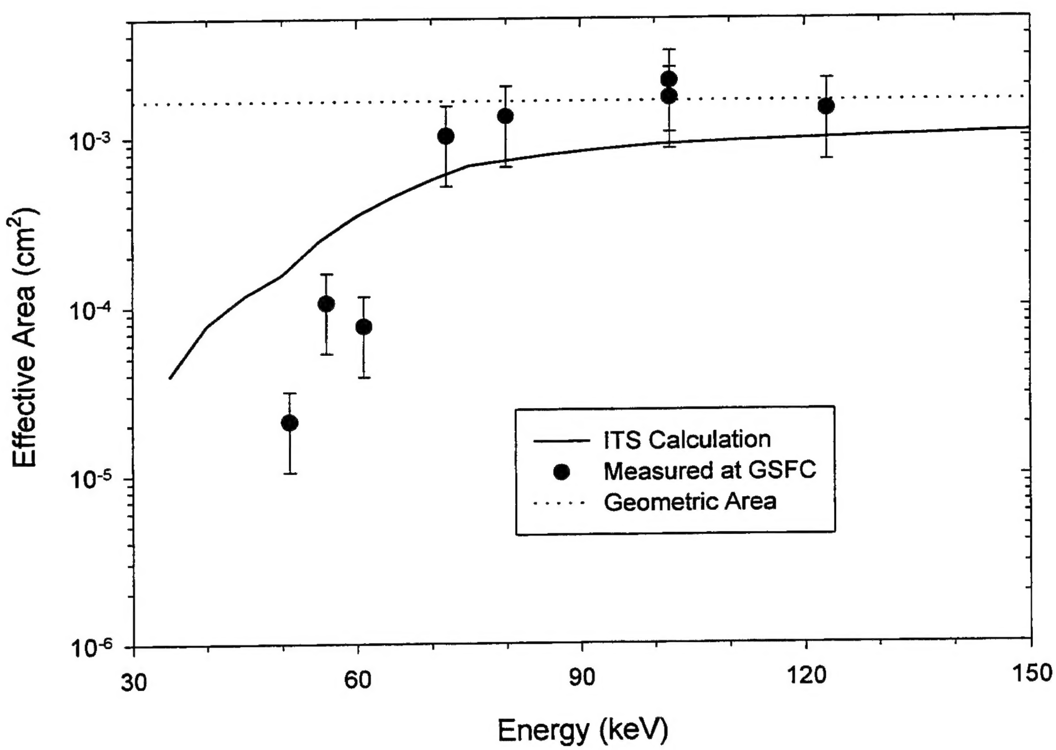

Figure 12. CEASE telescope response for normally incident electrons.

based on the collimator geometry but neglecting the angular scattering in the Al foil covering the entrance aperture. The increase in width of the measured response relative to the calculated one is due to the scattering in the Al foil, which is characterized by a distribution with a full-width-half-maximum of about 10 degrees.

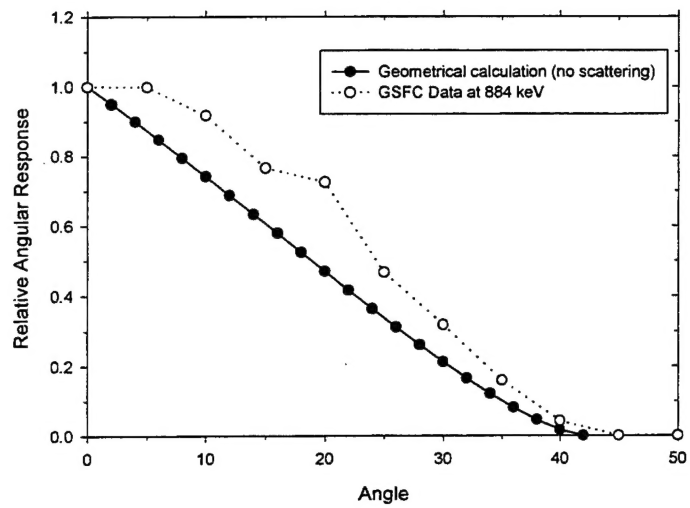

Figure 13. Telescope angular response.

The measured telescope angular responses were used to determine the energy dependent effective geometric factors (see Figure 14). The SDC channels are LB's (1,0), (2,0) and (3,0) (see Figure 4), which are used to determine the level of threat from surface dielectric charging from low energy electrons. All proton counts in these LB's will be misinterpreted as electrons. The amount of proton contamination of SDC channels, calculated using the measured electron and proton responses, is listed in Table 5 for a variety of space environments.

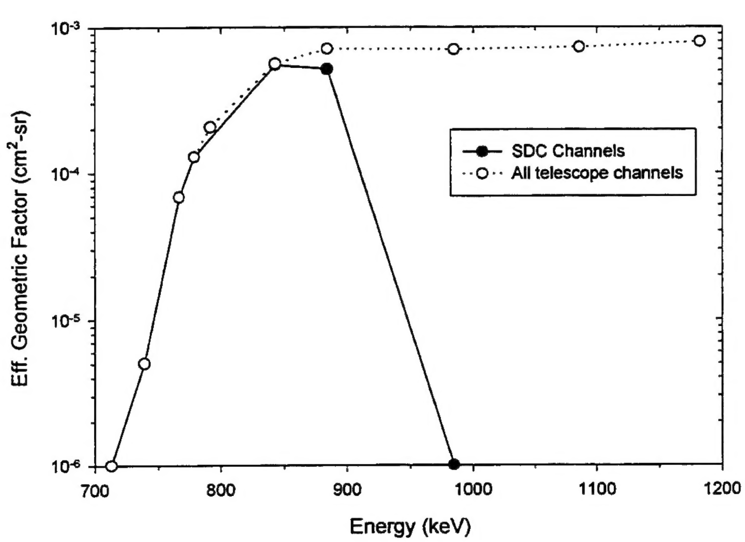

Figure 14. Telescope Effective Geometric Factors.

Table 5. Listing of CEASE SDC channel responses.

CEASE Response (Counts/sec)	Space Environment							
	IZ	Slot	OZ	W. Strm.	L. Strm.	L1	L2	L3
Electrons	13,200	9,900	2,662	16,816	142,300	73	731	7,310
Protons	0.30	23.0	118.3	0.015	0.78			

Notes:

IZ is the inner radiation zone
Slot is the region between the inner and outer zones
OZ is the outer radiation zone
W. Strm. is a weak solar storm as experienced at geo-synchronous orbit
L. Strm. is a very strong solar storm
L1 is a flux level of 5 $x10^5$ electrons / cm^2-sec
L2 is a flux level of 5 $x10^6$ electrons / cm^2-sec
L3 is a flux level of 5 $x10^7$ electrons / cm^2-sec

8. CONCLUSIONS

The delivery of two CEASE flight units and one CEASE engineering unit on 30 April 1996 was a culmination of five years of effort.

The first phase of the CEASE contract (years 1 and 2) were devoted to developing the CEASE instrument design concept and to predicting the instrument's response in a variety of space environments. At the end of this phase, a conceptual CEASE design was presented to Phillips Laboratory for approval for actual development. The design envisaged an instrument 4 in x 4 in x 4 in, weighing about 2 lbs., using 2-3 Watts, and capable of providing warnings to the host spacecraft of surface and deep dielectric charging, radiation dose effects and single event upsets.

Following approval from Philips Laboratory, the second phase of the contract (hardware development) begun. This phase took place during contract years 3 through 5. The work performed included: (1) detailed electronic design, (2) detailed mechanical design, (3) manufacture and testing of printed circuit boards, (4) manufacture and testing of the mechanical design, (5) instrument integration, (6) thermal vacuum testing, (7) vibration testing, and (8) radioactive source and beam calibrations.

The instruments as delivered to Phillips Laboratory are not only capable of providing spacecraft environment warnings specified in the conceptual design, but can also provide high quality science data, if sufficient spacecraft telemetry is available (approximately 45-90 bps). The delivered CEASE instruments are 4 in x 4 in x 3.2 in, have a mass of 1 kg (2.2 lbs) and use less than 1.5 Watts(if equipped with an RS-422 interface).

The dual goals of the CEASE program were:(1) to develop a small, low-power instrument for providing warnings of environmental hazards to the host spacecraft and (2) to advance the state-of-the-art in the technology of spacecraft instrument miniaturization. We believe that the delivered instruments represent the successful accomplishment of both program goals.